# Water Based Critical Utilities

# RO, WFI, and Steam

**The bottom of the iceberg that makes a plant run!**


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# Start With 4 Simple Questions

- What is the starting water quality?
- What is the water /steam quality that we need?
- What treatment processes are available and what does each process do?
- How do I get the water /steam from the point where it is produced to the points where it is used (without picking up contamination along the way) ?

# What public information is available from the local municipality ??

| Contaminant Detected | Unit | MCL | MCLG | Level Detected | Range of Detection | Major Sources | Violation |
|---|---|---|---|---|---|---|---|
| **Regulated Contaminants** | | | | | | | |
| Nitrate | ppm | 10 | 10 | 0.34 | N/A | Runoff from fertilizer use; leaching from septic tanks, sewage; erosion from natural deposits. | NO |
| Flouride *(see below) | | | | 1.17 | 0.88 to 1.17 | Water additive that promotes strong teeth. | NO |
| * State (MCL) | ppm | 2 | none | | | | |
| * EPA (MCL) | ppm | 4 | none | | | | |
| Sodium | ppm | none | none | 34.3 | N/A | Erosion of natural deposits; road salt, and water treatment chemicals. | NO |
| Chlorite | ppm | 1.0 | 0.8 | 0.50 | 0.21 to 0.50 | By-product of drinking water disinfection. | NO |
| Turbity (see note) | NTU | 1.0 | TT=100% | 0.17 | 0.06 to 0.17 | Soil runoff. | NO |
| TT= Lowest percentage of monthly samples <0.3 NTU<br>**Note:** Turbidity is a measure of the cloudiness of the water. We monitor it because it is a good indicator of the effectiveness of our filtration system. | | | | | | | |
| Disinfectant residual | ppm | (MRDL) 4 | (MRDLG) 4 | .97 | 0.42 to .97 | By-product of drinking water disinfection. | NO |
| Perchlorate | ppb | 2.0 | none | 0.33 | N/A | Rocket propellants, fireworks, munitions, flares, blasting agents. Aged water treatment disinfection chemicals | NO |

# What public information is available from the local municipality ??

| Contaminant Detected | Unit | MCL | MCLG | Level Detected | Range of Detection | Major Sources | Violation |
|---|---|---|---|---|---|---|---|
| **Volatile Organic Contaminants** | | | | | | | |
| (TTHM) | ppb | 80 | 0 | (50) | 0.5 to 50.0 | By-product of drinking water chlorination. | NO |
| [Total Trihalomethanes] | | | | (Highest Runing Annual Average) | | | |
| **Disinfection By-Product Contaminants** | | | | | | | |
| (HAA) | ppb | 60 | 0 | (20.7) | 0 to 20.7 | By-product of drinking water chlorination. | NO |
| [Halo-acetic Acids] | | | | (Highest Runing Annual Average) | | | |
| **Unregulated Contaminants** | | | | | | | |
| MTBE | ppb | none | none | N/D | N/D<0.05 | Gasoline Additive. | NO |
| Chloroform | ppb | none | none | 15.1 | 3.9 to 15.1 | By-product of drinking water chlorination. | NO |
| Bromodichloromethane | ppb | none | none | 7.3 | 2.2 to 7.3 | By-product of drinking water chlorination. | NO |
| Chlorodibromomethane | ppb | none | none | 2.5 | N/D<0.6 to 2.5 | By-product of drinking water chlorination. | NO |
| Sulfate | ppm | none | none | 5.0 | 5.0 | Mineral and nutrient | NO |

# What public information is available from the local municipality ??

| Contaminant Detected | Unit | MCL | MCLG | Level Detected | Range of Detection | Major Sources | Violation |
|---|---|---|---|---|---|---|---|
| **Radionuclides** | | | | | | | |
| Gross Alpha | pCi/l | 15 | 0 | 0.5 (+-1.1) | N/A | Erosion of natural deposits | NO |
| Radium 228 | pCi/l | 5 | 0 | 0.1 (+-0.6) | N/A | Erosion of natural deposits | NO |
| Contaminant | Unit | MCL | MCLG | Level Detected | Range of Detection | Major Sources | Violation |
| Lead | ppb | 15 | 0 | .001 | 0 of 50 | Corrosion of household plumbing systems. Erosion of natural deposits. | NO |
| Copper | ppm | 1.3 | 1.3 | 0.04 | 0 of 50 | Corrosion of household plumbing systems. Erosion of natural deposits; Leaching from wood preservatives. | NO |

Finished water pH ranged from 7.5 to 8.3

# What we really need to know

| Parameter | Method | Result | MRL |
|---|---|---|---|
| **- City Water** | | | |
| *Sampled: 10/2/2013 by Client* | | | |
| Barium, MG/L | EPA 200.7 | 0.024 | 0.001 |
| Boron, MG/L | EPA 200.7 | 0.02 | 0.01 |
| Calcium, MG/L | EPA 200.7 | 38.2 | 1 |
| Magnesium, MG/L | EPA 200.7 | 2.8 | 1 |
| Potassium, MG/L | EPA 200.7 | 4.2 | 1 |
| Silica as SiO2, MG/L | EPA 200.7 | 8.5 | 1 |
| Sodium, MG/L | EPA 200.7 | 99.3 | 1 |
| Strontium, MG/L | EPA 200.7 | 0.181 | 0.001 |
| Ammonia, MG/L | SM 4500-NH3-D | ND | 0.1 |
| Bicarbonate, MG/L | SM 2320B | ND | 1 |
| Carbonate, MG/L | SM 2320B | 75 | 1 |
| Chloride, MG/L | EPA 300.0 | 164 | 1 |
| Fluoride, MG/L | EPA 300.0 | ND | 0.1 |
| Nitrate as N, MG/L | EPA 300.0 | 0.24 | 0.05 |
| Sulfate, MG/L | EPA 300.0 | 10.8 | 1 |

# Let's understand what has to be removed

## Classify the various contaminants

- Particles or Suspended Solids
- Dissolved Solids
  - Ionized
  - Non-ionized
  - Organic
- Colloidal Materials
- Dissolved Gases
- Bacteria and other living organisms

## Contaminants introduce variability !!

# Particles or Suspended Solids

Materials that do not dissolve in water

Can be any shape

- Mostly considered as hard, spherical particles

Moving water holds more particles

Larger and more dense particles will settle out by themselves

Smaller particles may never settle

# Dissolved solids, Ionized

Materials that dissolve in water

Form free floating ions in solution

- Adds positive and negative charges to a solution
- Solution remains electrically neutral

The ionized solids content changes how much electricity the water can conduct

Direct relationship between the abundance of ions and the conductivity of the water

# Dissolved solids, Non-Ionized

Materials that dissolve in water

Do not form free floating ions in solution

No charge is added to the solution

No change in the conductivity of the solution

Cannot measure abundance by measuring conductivity

# Dissolved solids, Organic

Materials that dissolve in water and contain carbon

May add a slight charge to a solution

Small in size, so these materials are very difficult to remove from a solution

Cannot measure abundance by measuring conductivity

# Colloidal Materials or Suspensions

Contain carbon

Large in molecular size (10,000-5,000,000 MW)

Slightly negative charge

Somewhere between suspended and dissolved

- Too small to settle by themselves
- Held in solution by size and charge repulsion

Undetectable change in the conductivity

Measure abundance by silt density index

Can plug up purification processes

# Dissolved Gases

**Nitrogen, oxygen, carbon dioxide, etc.**

- Not removed by most purification processes
- More dissolved gases in solution at lower temperatures (opposite of dissolved solids)
- Least understood and least studied contaminant
- Carbon dioxide is troublesome because it ionizes when it dissolves into solution
- Ammonia can be troublesome to some purification processes in waters treated with chloramine
- Present as a contaminant in clean steam as non condensible gases

# Bacteria and other living organisms

**Not uniformly distributed in a water system**

- Exist in equilibrium with their environment
- More food = more bacteria
- Less than 1% is free floating (detectable)
- Vast majority is present as biofilm
- Compete for Nutrients with the cells we want

# Where does our water come from?
# How do it properties vary?

## Well Water

Low Suspended Solids

High Dissolved Salts

Low Colloidal Content

Some Dissolved Gases

## Surface Water

High Suspended Solids

Low Dissolved Salts

High Colloidal Content

High Dissolved Gases

# What water quality do we really need ?

# It depends !

## Where are we in the product's life cycle ?

***Drug Discovery***

***Research*** ***Pilot Scale***

***Clinical Trials***

***Full Scale Manufacturing***

# Labs use CLSI/NCCLS or ASTM specifications for purity

| PARAMETER | CLSI/NCCLS | | | ASTM | | | |
|---|---|---|---|---|---|---|---|
| | TYPE 1 | TYPE 2 | TYPE 3 | TYPE 1 | TYPE 2 | TYPE 3 | TYPE 4 |
| Conductivity (max) | <0.1 | <0.2 | <0.5 | 0.056 | 1.0 | 0.25 | 5.0 |
| Resistivity (min) | >10.0 | >2.0 | >1.0 | 18.0 | 1.0 | 4.0 | 0.2 |
| pH | --- | --- | --- | --- | --- | --- | 5.8-8.0 |
| Silica (ppb) | <500 | <100 | <1000 | 3 | 3 | 500 | ---- |
| Sodium (ppb) | --- | --- | --- | 1 | 5 | 10 | 50 |
| Chlorides | --- | --- | --- | 1 | 5 | 10 | 50 |
| Total Organic Carbon (ppb) | --- | --- | --- | 100 | 50 | 200 | --- |
| Bacteria (cfu/ml) | <10 | 10 | --- | Separate specification, only where bacteria control is required<br>Type 1 : 10/1,000 ml<br>Type 2 : 100/1,000 ml<br>Type 3 : 10,000/1,000 ml | | | |

# Dialysis has their own requirements

**CHEMICAL CONTAMINANTS & MAXIMUM ALLOWED (MG/L**

| | | | |
|---|---|---|---|
| Aluminum | 0.01 | Lead | 0.005 |
| Antimony | 0.006 | Magnesium | 4 (0.3mEQ/L) |
| Arsenic | 0.005 | Mercury | 0.0002 |
| Barium | 0.10 | Nitrate | 2.0 |
| Beryllium | 0.0004 | Potassium | 8 (0.2 mEq/L) |
| Cadmium | 0.001 | Selenium | 0.09 |
| Calcium | 2 (0.1mEQ/L) | Silver | 0.005 |
| Chloramines | 0.10 | Sodium | 70 (3.0 mEq/L) |
| Chromium | 0.014 | Sulfate | 100.0 |
| Copper | 0.10 | Thallium | 0.002 |
| Fluoride | 0.20 | Zinc | 0.10 |
| Free Chlorine | 0.50 | | |

| BACTERIA | MAXIMUM ALLOWED |
|---|---|
| Water used for dialysate → *(RD52,4.1.2)* | <200 CFU/ml<br>Endotoxin level <2 EU/ml |
| Dialysate → → → *(RD52, 4.3.2.1)* | <200CFU/ml<br>Endotoxin level <2 EU/ml |

# Microelectronics requirements are unbelievable !



| PARAMETER | ATTAINABLE | ACCEPTABLE | ALERT | CRITICAL |
|---|---|---|---|---|
| Resistivity | 18.2 | 18.2 | 17.9 | 17.5 |
| TOC (online, ppb) | <1 | <2 | 5 | 10 |
| THM (ppb) | <2 | <5 | --- | --- |
| Particles by laser<br>0.05 to 0.1 micron<br>0.1 to 0.2 micron<br>0.2-0.3 micron<br>0.3-0.5 micron<br>>0.5 micron | <100/1000 ml<br><50/1000 ml<br><20/1000 ml<br><10/1000 ml<br><1/1000 ml | <500/1000 ml<br><300/1000 ml<br><50/1000 ml<br><20/1000 ml<br><4/1000 ml | | |
| Bacteria (cfu/1000 ml) | <1 | <6 | 25 | >25 |
| Silica (total, ppb) | <0.5 | <3 | >5 | >10 |

| PARAMETER | ATTAINABLE | ACCEPTABLE | ALERT | CRITICAL |
|---|---|---|---|---|
| Phosphate (ppb) | <0.02 | <0.1 | >0.01 | >0.5 |
| Silicate (ppb) | <0.05 | 0.1 | <0.02 | >0.5 |
| Sodium (ppb) | <0.01 | 0.05 | >0.02 | >0.5 |
| Potassium (ppb) | <0.02 | <0.1 | >0.02 | >0.5 |
| Ammonium (ppb) | <0.06 | 0.1 | <0.02 | >0.5 |
| Calcium (ppb) | <0.02 | <0.1 | >0.01 | >0.2 |
| Magnesium (ppb) | <0.02 | <0.1 | <0.01 | >0.2 |
| Fluoride (ppb) | <0.1 | <0.1 | >0.02 | >0.5 |
| Chloride (ppb) | <0.02 | 0.1 | <0.02 | >0.5 |
| Bromide (ppb) | <0.02 | <0.1 | >0.01 | >0.5 |
| Nitrate (ppb) | <0.02 | <0.1 | <0.01 | >0.5 |

| METAL ION CONTAMINANTS, ALL ARE MEASURED IN PARTS PER TRILLION | | | | |
|---|---|---|---|---|
| Aluminum (ppt)* | 7 | 50 | >0.0 | 200 |
| Barium (ppt)* | 2 | 10 | >50 | 100 |
| Boron (ppt)* | 300 | <2000 | | |
| Chromium (ppt)* | 8 | 30 | >30 | 50 |
| Copper (ppt)* | 5 | 50 | >50 | >200 |
| Iron (ppt)* | 10 | 100 | 200 | >200 |
| Lithium (ppt)* | 4 | 30 | 100 | >100 |
| Magnesium (ppt)* | 2 | 20 | 100 | >200 |
| Manganese (ppt)* | 4 | 30 | >30 | 100 |
| Nickel (ppt)* | 5 | 50 | >50 | 100 |
| Sodium (ppt)* | 10 | 60 | >200 | >500 |
| Strontium (ppt)* | 2 | 10 | >10 | >10 |
| Zinc (ppt)* | 8 | 60 | >50 | >100 |

# Pharmaceutical Water Quality

| PARAMETER | USP PURIFIED | USP WFI |
|---|---|---|
| Total Organic Carbon (ppb) | 500 | 500 |
| Conductivity | <1.3 @ 25°C | <1.3@25°C |
| Bacteria | None given, but recommended to be 100/ml | None given, but recommended to be 10/100 ml |
| Endotoxins | ---- | <0.25 EU/ml |

## Hey, Why Is Injectable Grade Water Allowed To Have Bacteria ??

## #3 What water purification processes are available?

# What does each one actually DO?

Particle filters remove contaminants based on their size

Ion exchange removes contaminants based on their charge

# Carbon filters remove small (below 1,000 MW) non polar molecules

**Remove disinfectants from drinking water**

**Protects chlorine sensitive reverse osmosis membranes**

# Ultraviolet units come in two basic flavors

Single wavelength
units (254 nm)
for bacterial control

Dual wavelength
units (185 & 254 nm) for
organics and bacteria control

Dual wavelength units (185 & 254 nm) increase the conductivity of the water, so location is extremely important

# Ozone Generators are becoming more popular

Oxidizes organics

Kills bacteria

Consumes biofilm

But, misapplication and misuse of ozone technology has led to problems, making many users reluctant

# Distillation is the only water treatment process that removes the water from the contaminants

Considered the gold standard
for producing
Water-For-Injection (WFI)
grade water

Dissolved gases and some
chemicals can carry over into
distillate (product water)

# Summary of Unit Operations

**Table 1 - Removal Capabilities of Various Water Purification Processes**

| | Coarse Particle Filters | Absolute Membrane Filters | Ultrafilters | Reverse Osmosis | Carbon Filtration | Ultraviolet Disinfection | Deionization |
|---|---|---|---|---|---|---|---|
| Particles | F | G-E | E | E | N | N | N |
| Dissolved Ions | N | N | N | G-E | N | N | E |
| Small Organics | N | N | N | F-G | G-E | N | P |
| Colloids | N | F-P | G-E | E | P-F | N | P |
| Bacteria | P | E | E | E | A | G | A-P |

N = None P = Poor F = Fair G = Good E = Excellent A = Adds contaminants to systems

# Sequencing of Unit Processes
# Varies between equipment manufacturers

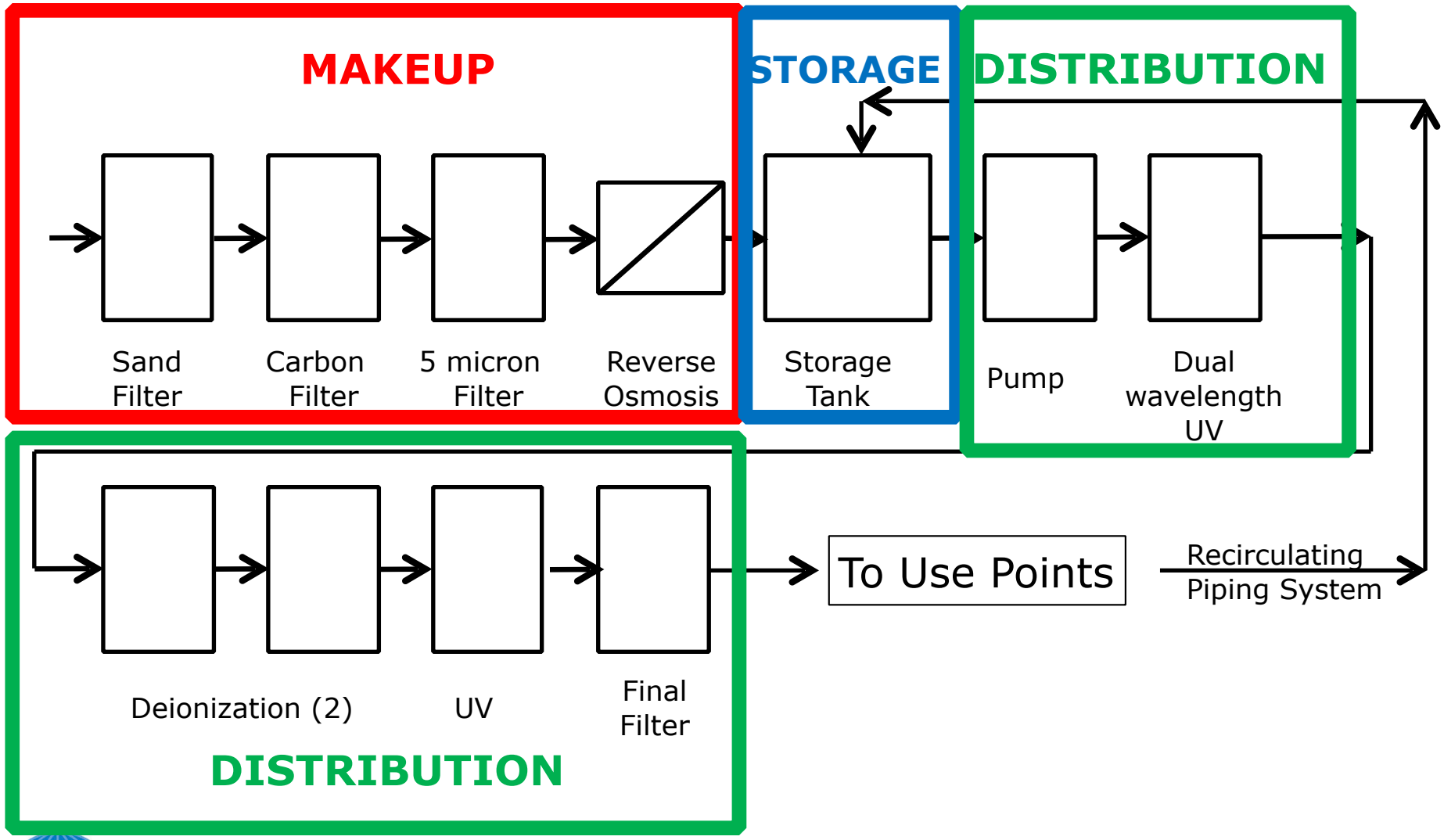
Remove Particles first
- Suspended Solids
- Colloidal materials

Remove dissolved ions next

Remove trace materials
- Ions, organics, particles
- System generated impurities

Remove bacteria as the last step

# Sequencing of Unit Processes
# Varies between equipment manufacturers



# Design of Distribution Piping Systems

Design around 5 feet per second (FPS) velocity

Design for 3 FPS in return with use points active

No dead legs (6D rule)

WFI water almost always piped in stainless steel

Purified water can be piped in SS, PP, PVDF

# Steam Systems

ISPE®

# Two Types of Steam Systems

Plant or Utility Steam

Clean or Pure Steam

# Plant or Utility Steam

Produced by a Carbon Steel Utility Boiler

Contains Additives to Prevent Corrosion

Elevated pH of ~10

Pressures in excess of 60 psi are common

# Clean or Pure Steam

Produced by a Clean Steam Generator

Characterized by

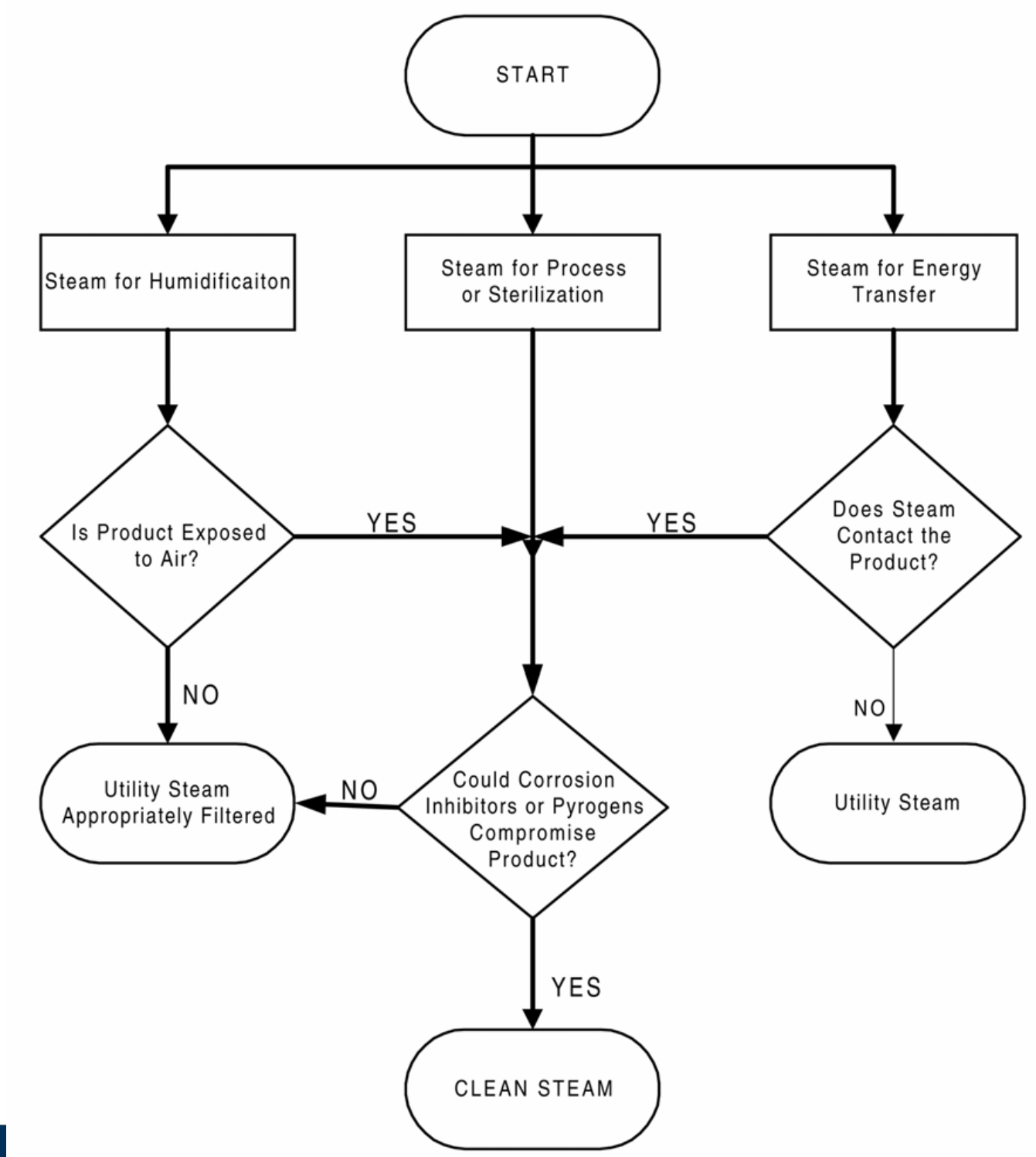
- No Additives
- pH below 7
- 15 psi pressure

Used in Pharmaceutical or Biotech Plants for

Thermal Disinfection ($10^5$ reduction)

Sterilization ($10^6$ reduction)

# What Type of Steam is Needed ?




*Source: ISPE Baseline Guide for Water and Steam Systems*

# Contaminants of Concern
# Clean or Pure Steam

Non Condensable Gases (3.5% Max)
    Creates cool spots
Water Droplets (Dryness 0.90 Min)
    Entrained moisture or condensate
    from high velocities
Superheated steam (25°C max over sat.)

Purity specified in British std EN 285

# Design of Distribution Piping Systems for Clean or Pure Steam

Surface finish is not as critical here
Slope in direction of flow
Maximum design velocity of 120 feet/sec
Ball valves are common practice
Condensate traps before use points
Non condensable gas vent at high point or in vessel

# QUESTIONS ??

# THANK YOU

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